Piezoelectric Carbon Nanotube Tape for use in Sensor Technology

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Co-Investigators

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Purpose of Program

- Purpose of research is to develop piezoelectric CNT tape for use as sensing elements in vibration gyroscopes and accelerometers for small satellites
- CNT/P(VDF-TrFE) tape has potential to be robust with high strength and superior thermal properties

Background

- Carbon nanotubes (CNT) have been of intense interest since discovery in 1991
- They exhibit superior mechanical and thermal properties as well as unique electrical properties
- CNTs can be either single-wall or multi-wall

Background

- Synthesis techniques include:

1. Arc Discharge

2. Laser Ablation

3. Plasma Torch

4. Chemical Vapor Deposition (CVD)

Background

CNT is one allotrope of carbon

Background

SWCNT   MWCNT
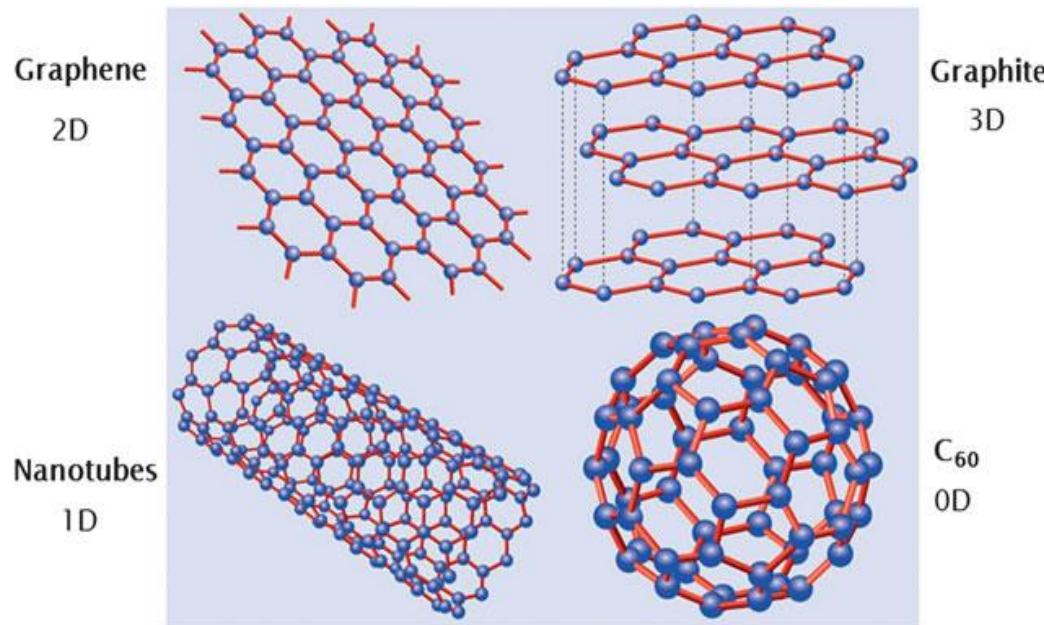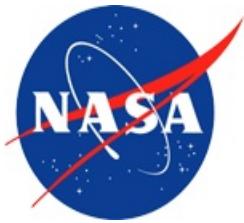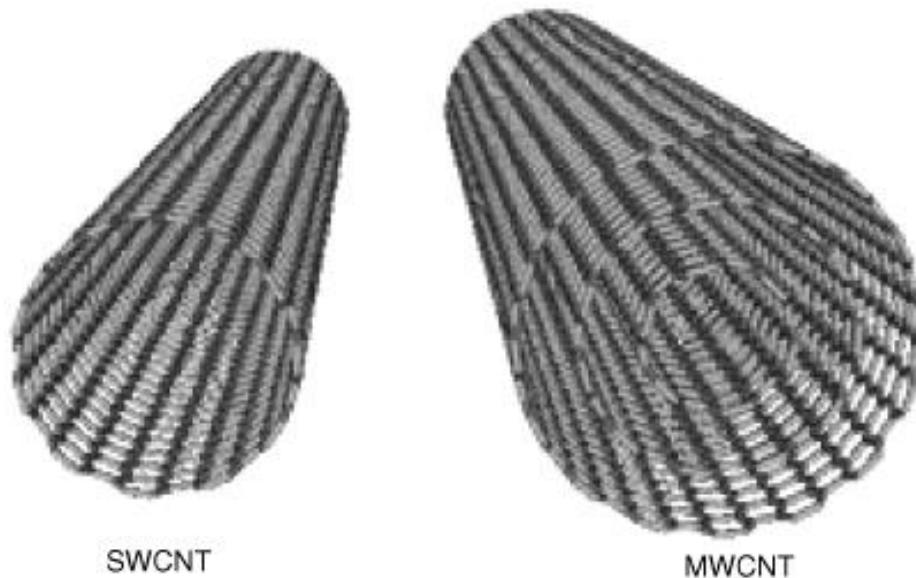
Background

CNTs Being Investigated for Various Sensors Including:

1. Pressure Sensors

2. Flow Sensors

3. Acoustic Sensors

4. Chemical Sensors

5. Temperature Sensors

Background

- We are interested in sensor applications for spacecraft including:

- Gyroscopes

- Accelerometers

- Structural Health Monitoring

- These will use CNT Tape as Active Elements
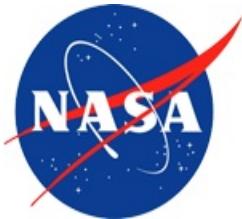
Experimental

- P(VDF-TrFE) (70/30) Copolymer dissolved in DMSO, 0.2 w/o, 5 w/o and 10 w/o
- Solution sprayed onto CNT tape as it is wound onto take-up reel; 100 micrometers thick
- Tape removed from reel and dried in vacuum oven at 100C for 24 hours
- Tape removed and pressed using glass weight above Curie Temperature to induce beta phase growth; 90 micrometers thick
- Beta phase is most polarizable of all the phases
- 10 w/o BaTiO3 added to solution to increase piezoelectric response
- Piezoelectric Effect measured using Radiant Technologies Tester
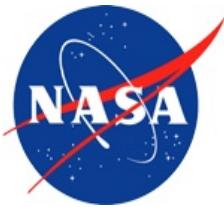
Experimental
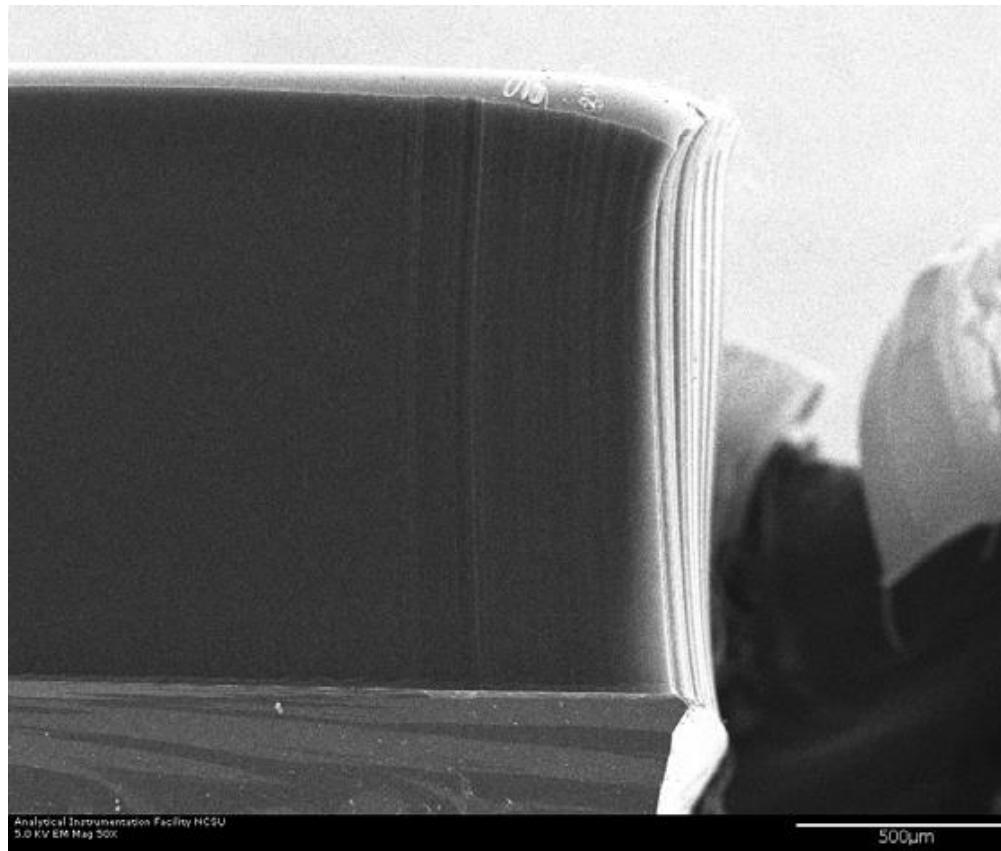
**1.5 millimeter tall vertically aligned carbon nanotube array grown on a silicon substrate.**
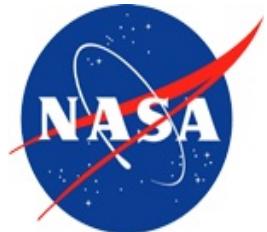
Production of CNT Tape
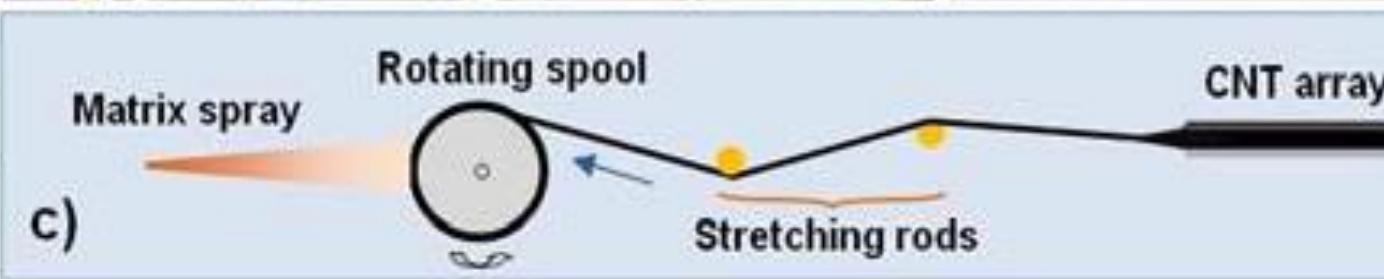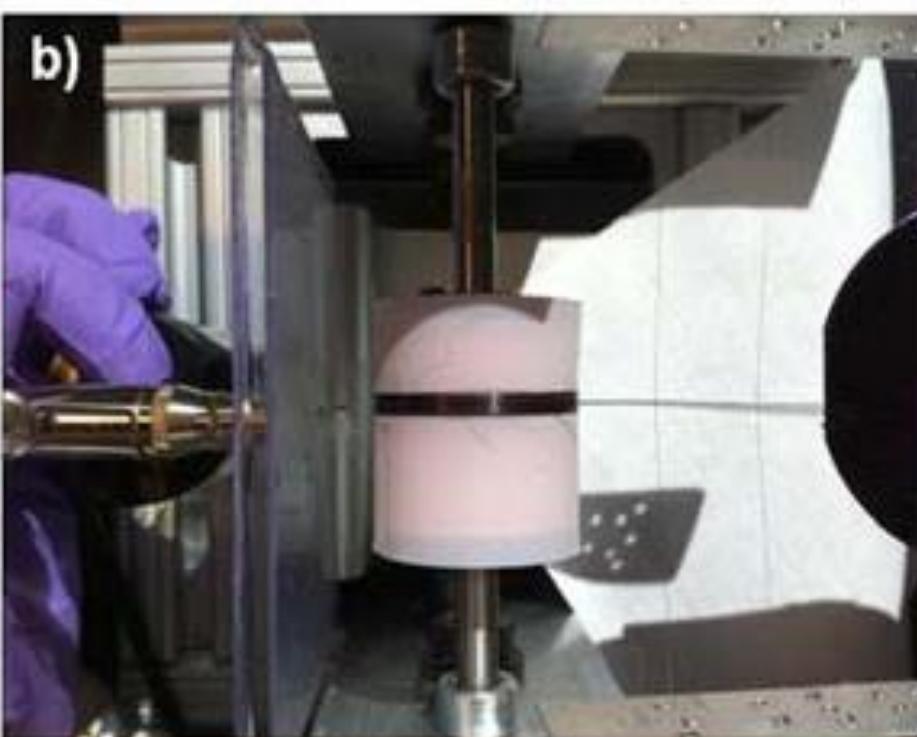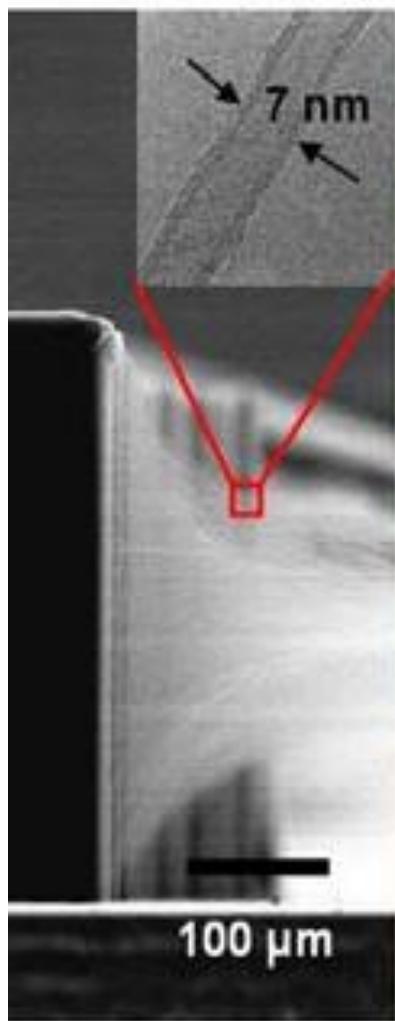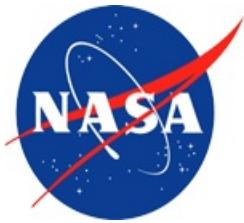
Results

Initial Hysteresis Curve for CNT/P(VDF-TrFE) 0.2 w/o
Pr = 16 uC/cm2 – Measured with Radiant Tester
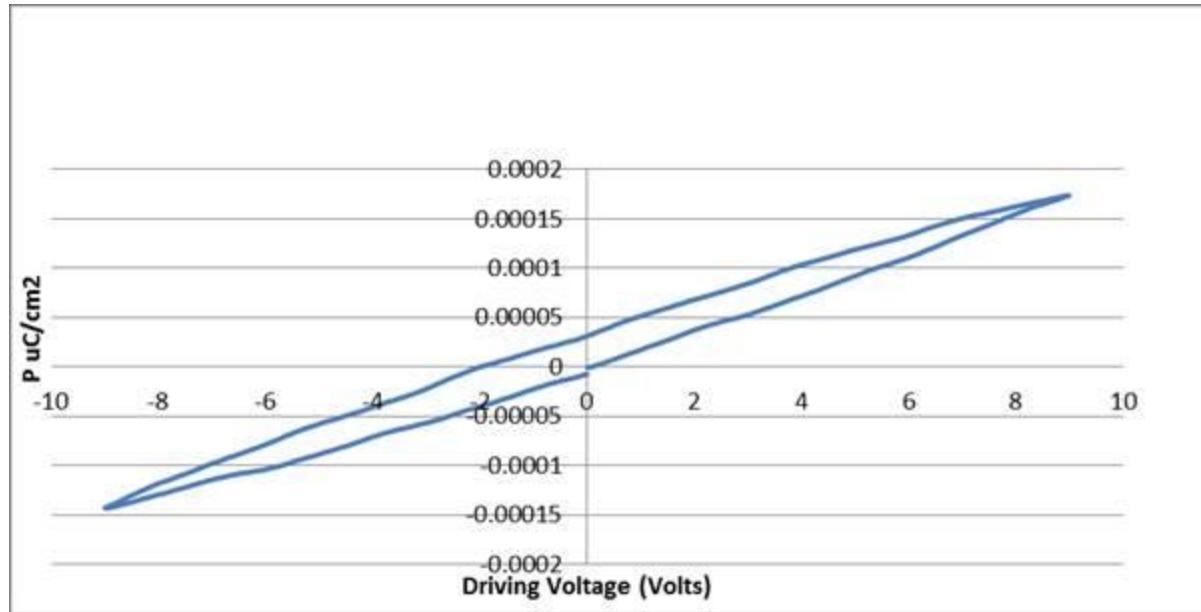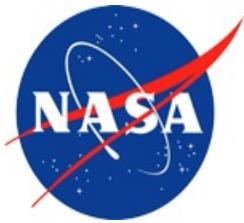
Results

Sample in Previous Slide Direct Poled at 10 Volts for 10 Minutes

Pr = 22 uC/cm2
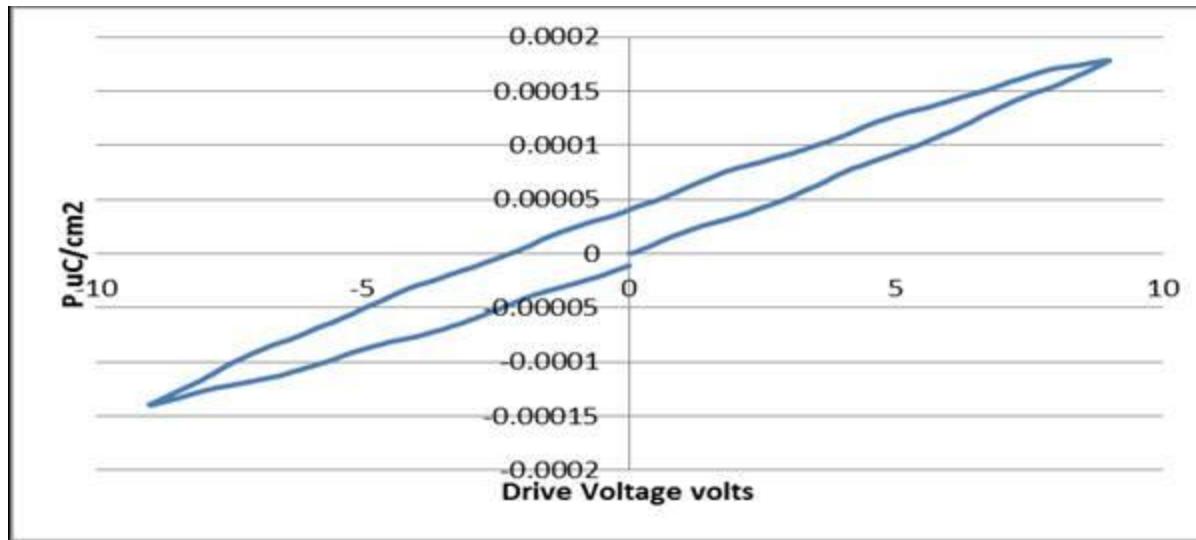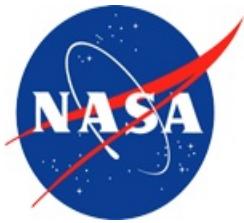
Results

SEM of 0.2w/o P(VDF-TrFE) CNT Tape

500X – SEM Image
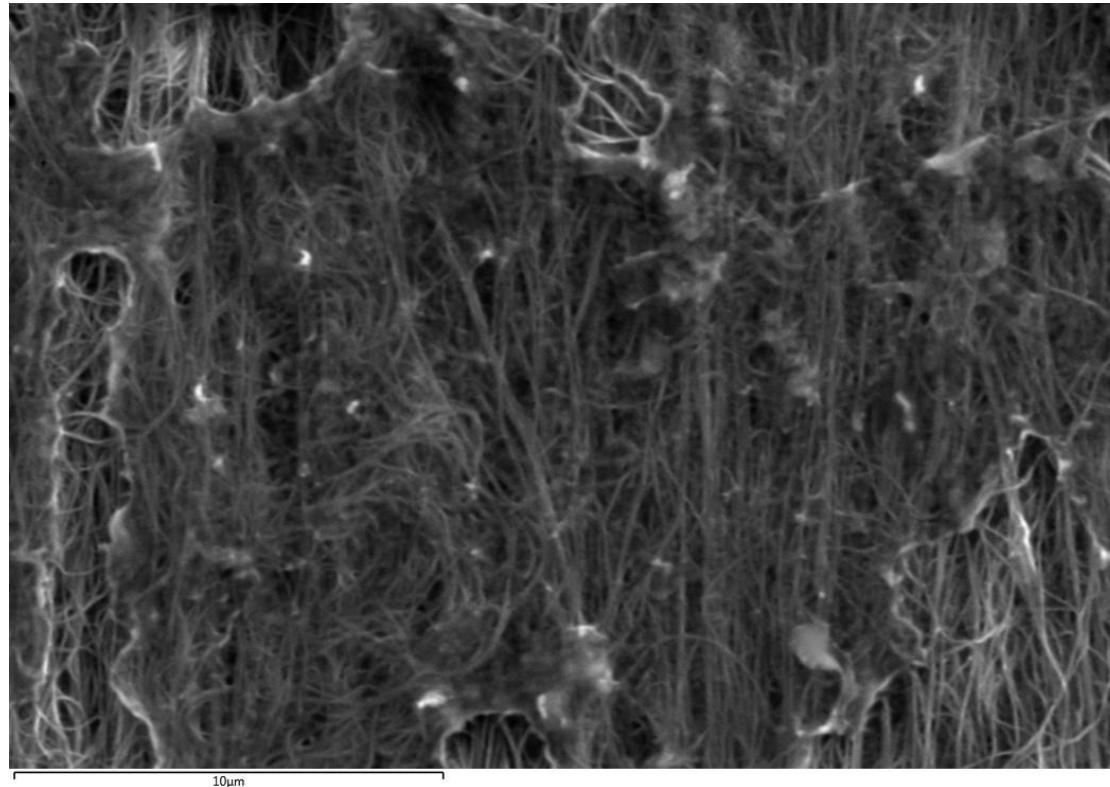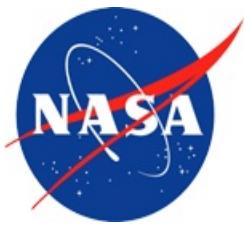
Corona Poling
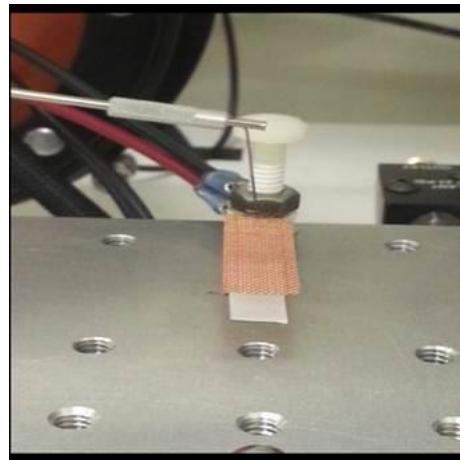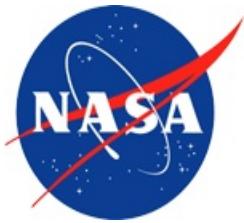
Results

CNT/P(VDF-TrFE)/BaTiO3 (10 w/o) Corona Poled at 2500 V for 20 Minutes
Pr = 61 uC/cm2
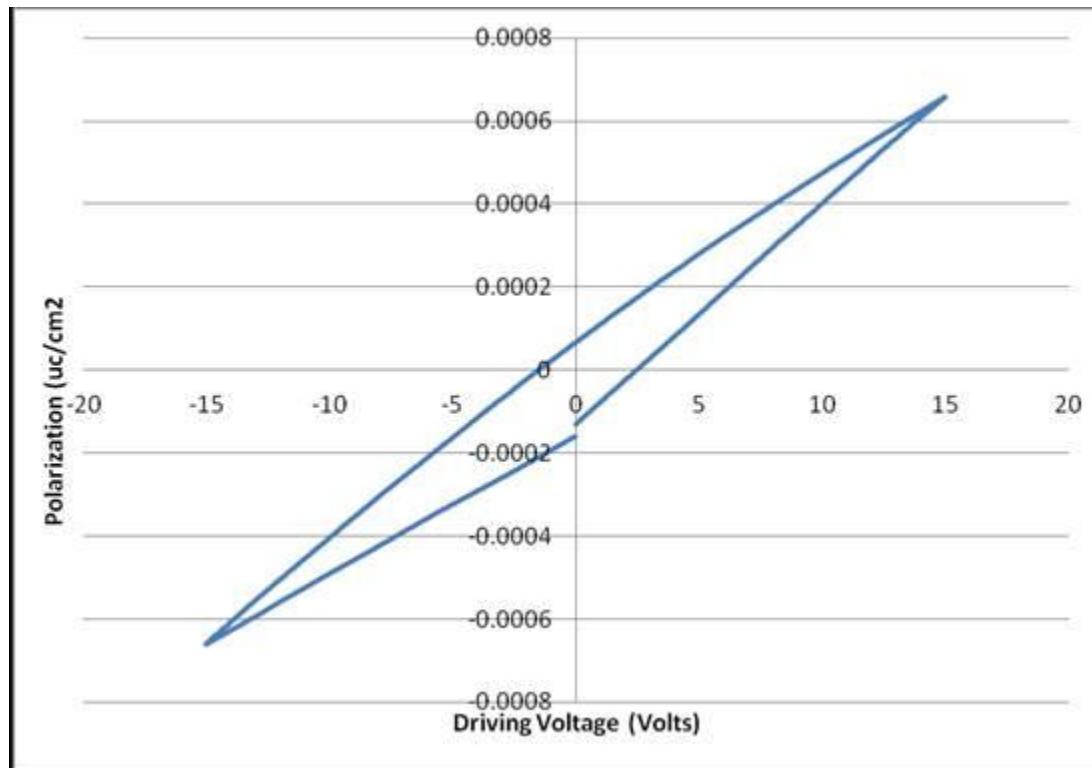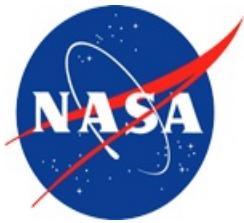
Results
SEM CNT/P(VDF)TrFe10/BT10

500X – SEM Image
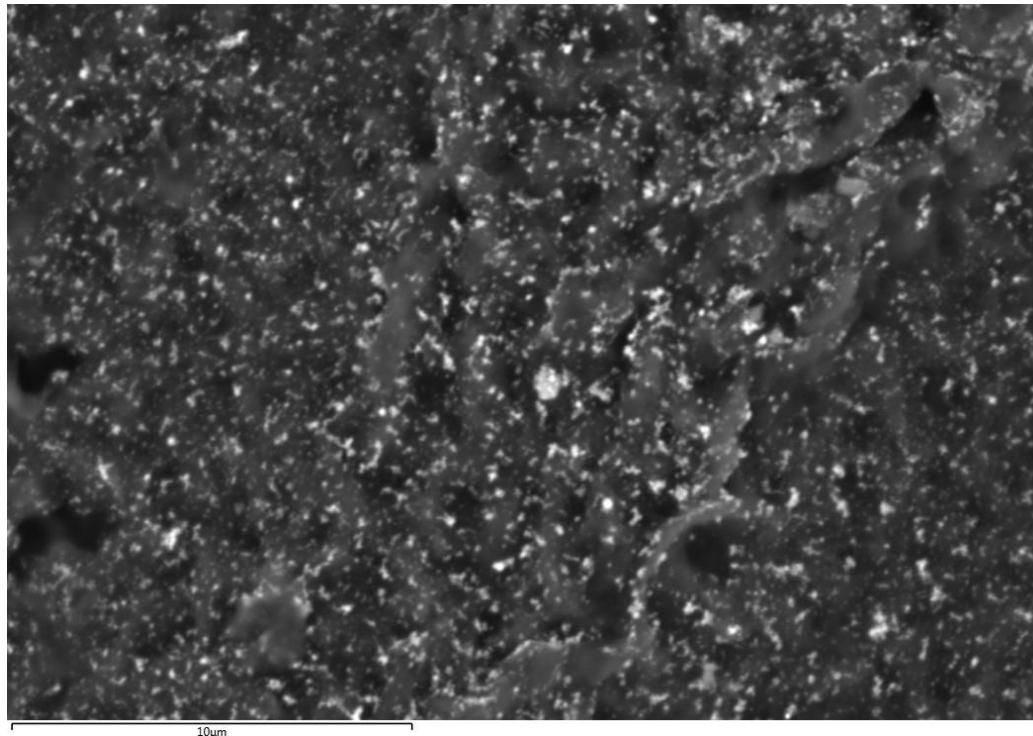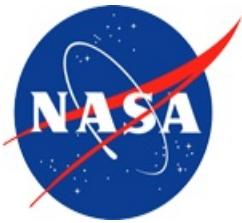
Piezoelectric Constitutive Equations

- $S_{ij} = s^E_{ijkl} T_{kl} + d_{kij} E_k$
- $D_i = d_{ikl} T_{kl} + \varepsilon^T_{ik} E_k$

Where:
- S_{ij} = strain components
- T_{ij} = Stress components
- E_k = electric field components
- D_k = displacement components
- d_{kij} = constants of the displacement matrix
- ε_{ij} = constants of electric field matrix

Piezoelectric Response Matrix

For PVDF Materials displacement matrix elements are:

- d_{31}, d_{32}, d_{33}, d_{25} and d_{15}
- The matrix is not fully populated due to the anisotropic nature of PVDF
- d_{ij} for our study: ratio of the strain in the j-axis to electric field applied along i-axis

**Figure 1.6** Directions of forces affecting a piezoelectric element
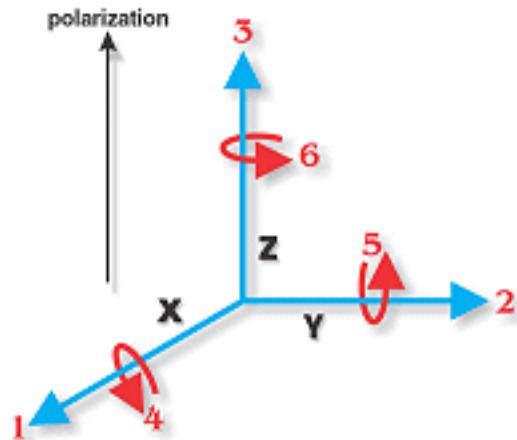
Diagram Source: APC Inc.
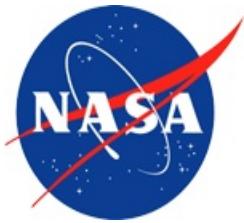
Results

Orientation of CNT Tape for Piezoelectric Measurements of d33

Apply voltage along 3 direction and Measure Response along
3 direction
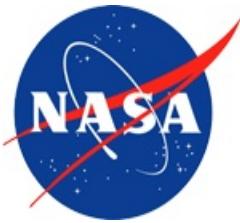
Results

- CNT/P(VDF-TrFE)/BT showed d33 of 140 pm/V

- Lit shows values from 1 – 34 pm/V

- Differences not only due to material but also sample thickness and polarization voltage

- Thin films with high voltage show highest values

- CNT/P(VDF-TrFE) films had d33 of 70 pm/V compared to 32-35 pm/V for pure P(VDF-TrFE) commercial film

- Due to Maxwell-Wagner-Sillars polarization – buildup of charges at interface of materials of different conductivity

- Dielectric constant of CNT/P(VDF-TrFE) was 161

- Lit values approximately 16 – These only had small w/o cnts (0.1 or less)

- These tapes had a tensile strength of 120 MPa and Young's Modulus of 17.8 GPa (Lit values of 68 MPa strength and 1.4 GPa Young's Modulus)

Results
FTIR Data
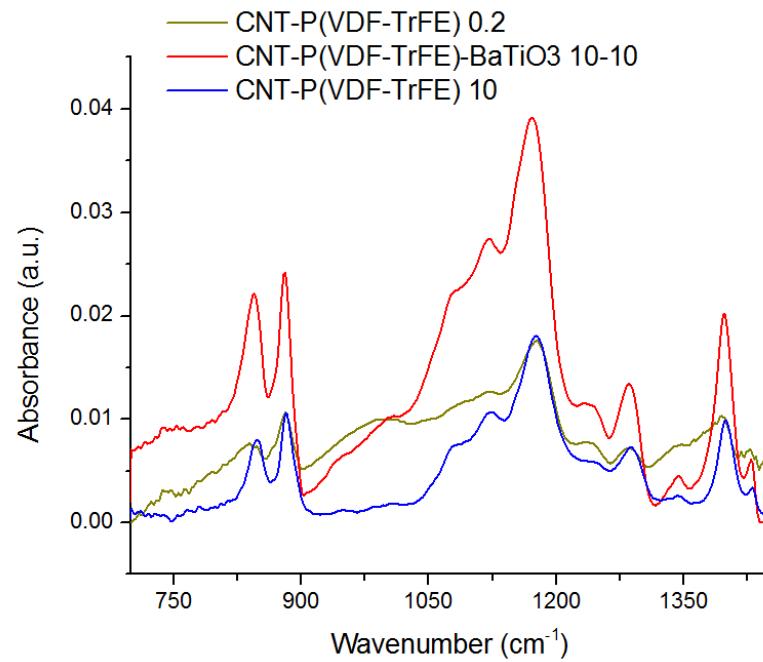
Beta Phase Wavenumbers: 840 and 1280
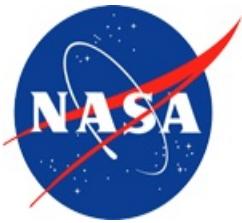
Results

| Material	Dielectric Constant	d_{33} (pm/V)
CNT/P(VDF-TrFE)	161	70
P(VDF-TrFE)/BT	204	140
CNT/P(VDF-TrFE)/BT	76	81

$g_{33} = d_{33}/\varepsilon$ (N/C) This gives idea of sensor value

Last material is only one with value > 1 so should be investigated further; also PZT as additive should be investigated
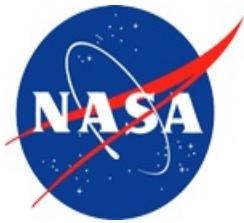
Future Work

- Achiral SWCNTs show mirror symmetries
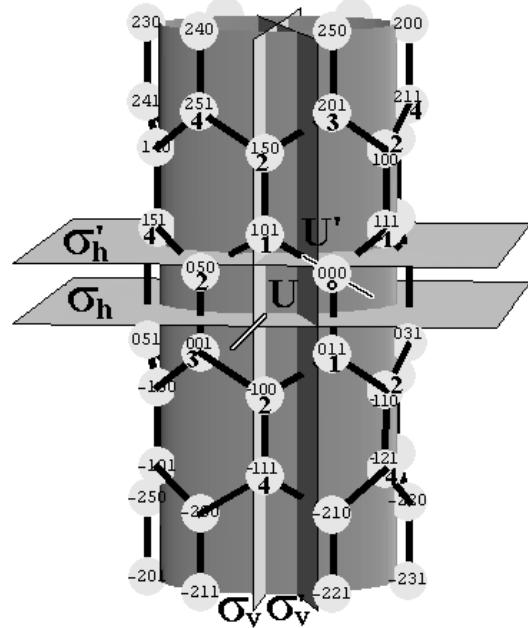
Inducing Piezoelectricity in CNTS

- Theoretically, it is possible to induce piezoelectric effect in CNTS

- Break mirror symmetry by adsorbing ions on one end or side of CNTS – Will try ion implantation

- Will try potassium initially on one end of vertical array

- Draw into CNT sheets and reinforce with BMI: Previous testing showed Tensile Strength of 3.8 GPa and Thermal Conductivity of 40 W/m K

- Also will take sheets and ion implant one side

- Test for Piezoelectric Effect